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ROTATION EXPERIMENTS:

Paulding, Henry and Madison Counties

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ROTATION EXPERIMENTS: PAULDING, HENRY AND MADISON COUNTIES

C. J. WILLARD[1]

This is a report of rotation experiments conducted by the Ohio Agricultural Experiment Station on the Paulding County Experiment Farm at Paulding, the Northwestern Experiment Farm at Holgate, and the Madison County Experiment Farm at London, under Project B. J. 12. This project, entitled "A study of the causes of deterioration in structure of Ohio soils and of methods of restoring a favorable structure, with special emphasis upon the reciprocal relationship between soil structure and root growth", was initiated by Richard Bradfield and C. J. Willard in 1936. Dr. Bradfield left Ohio in 1938 and leadership of the project was assumed by L. D. Baver. The experiment at the Northwestern Experiment Farm at Holgate was started in 1939, with Dr. Baver responsible for soil structure studies and C. J. Willard responsible for crop plans and yields.

Dr. Baver left Ohio in 1940, and leadership of the general project was assumed by Byron T. Shaw. The project on the Madison County Experiment Farm was laid out in the fall of 1940 and first harvests made in 1941. On this farm, C. J. Willard, R. D. Lewis, M. A. Bachtell, and H. W. Rogers were responsible for the rotation plan and obtaining yields. The project leader was to use the plots for soil structure studies as soon as sufficient time had elapsed for difference in structure to develop. Dr. Shaw left Ohio in March 1943 and J. B. Page succeeded to leadership of the project. The same division of responsibility continued.

Dr. Page left Ohio in 1950 and George S. Taylor[2] became leader of the general project. The Paulding County Experiment Farm was discontinued early in 1950, so that the 1949 yields were the last obtained.

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[2]In addition to these former leaders, the author wishes also to acknowledge gratefully the assistance of others concerned with the project: M. A. Bachtell, who was supervisor of the work on the outlying farms through 1947; T. F. Wonderling, who succeeded him in 1948; and especially the farm managers who were responsible for the day-to-day operations of the experiments: Rando C. Beatty at the Paulding County Experiment Farm; W. A. Trumphour, Serge Harmon, and Orrin Nichols at the Northwestern Experiment Farm; and H. W. Rogers at the Madison County Experiment Farm.

The lease on the Northwestern Experiment Farm expired in March, 1951, and the 1950 data were the last from there. The Madison County Experiment Farm was discontinued November 1, 1957, and that experiment was continued through 1957. Two graduate students have used samples from these rotations as material for soil structure studies. These reports (1) (9) are not reviewed here. Much of the data from these experiments has been partially presented before (3, 4, 11, and elsewhere).

THE PAULDING EXPERIMENT

The Paulding experiment was established on Blocks M, N, and O of the Paulding County Experiment Farm, located just south of Paulding. The soil is now (6) classified as Latty clay. It was called Paulding clay when the test was started. The soil was laid down as slack water deposits in glacial Lake Maumee. Latty clay is described as follows (6):

"**Latty clay** is a very poorly drained soil found on broad flats lying between major areas of Paulding clay and Hoytville clay present in the southwestern part of the county. It differs from Paulding clay in having less than 42 inches of very heavy, impervious water-laid clay material over glacial till. Latty soil, containing from 50 to 60 percent of clay in the subsoil, is heavier than Hoytville soil, which contains less than 50 percent of clay. It is not as heavy as Paulding soil.

"The brownish-gray to dark gray clay topsoil is moderately high in organic matter. It is 6 to 8 inches deep, sticky when wet, hard when dry, and is somewhat difficult to work. The gray and yellowish-brown subsoil is an impervious, compact, and heavy material that contains between 50 and 60 percent of clay. The glacial clay till parent material is less compact, less impervious and coarser textured than the subsoil.

"This soil is difficult to drain with tile. Surface drainage, when it is properly installed, may be used advantageously to remove excess surface water. This aids in obtaining better stands of crops.

"As on Paulding clay, heavy rains tend to cause the surface of this soil to seal over with fine clay particles bringing about the loss of much topsoil by being carried in suspension in surface runoff. When good tilth is present, crops do not suffer from inadequate moisture except during a very severe drouth.

"Latty clay works somewhat easier than Paulding clay, but since it dries slowly in the spring, it is often worked too wet. This soil is usually high in phosphorus and potassium, but occasionally some lime may be needed. Like Paulding clay the major fertility problem is associated with the problem of soil tilth. This soil responds favorably to the return of organic matter to the soil. Organic matter helps to increase the effectiveness of tile drainage, the ease of working the soil, and in making plant food available to the growing crop.

"When good tilth is maintained, all crops grown in the area are adapted to this soil."

This soil had been almost entirely unresponsive to fertilizers, both in tests at the Paulding County Experiment Farm and in the experience of farmers.

The cropping history of these plots for the 21 preceding years is given in Table 1, taken from the annual reports of the farm. This indicates that these plots had grown sod crops more often than the average farm in the area until 1929, but from 1929 to 1935 they had grown grain crops almost entirely. The corn yields in each of the first two years of the experiment, before the rotations had affected the yields. averaged 50 bushels per acre, ranging from 42 to 62 bushels.

The rotations and the plots on which they were established were as follows:

	Rotation	Plots
	Block M	
A.	Corn, oats, alfalfa (1), alfalfa (2)	1, 3, 5, and 7
B.	Corn, oats, alfalfa-brome (1), alfalfa-brome (2)	2, 4, 6, and 8
M.	Alfalfa, continuous	9 and 10
	Block N	
C.	Corn, oats, alfalfa	11, 14, and 17
D.	Corn, oats, sweetclover-orchardgrass	12, 15, and 18
E.	Corn, soybean seed, oats(sweetclover)	13, 16, and 19
N.	Bluegrass, continuous	20
	Block O	
F.	Corn, oats(sweetclover)	21 and 24
G.	Corn, oats—residues returned(no sweetclover)	22 and 25
H.	Corn, oats—residues removed(no sweetclover)	23 and 26
K.	Soybean hay; continuous, taken off	27
L.	Soybean seed, continuous, straw returned	28
I.	Corn, continuous, stalks returned	29
J.	Corn, continuous, stalks removed	30

The plots were numbered consecutively from south to north. Each plot was 27 × 200 feet, including a 3-foot border. The corn plots consisted of seven rows 40 inches apart, with rows 2, 3, 5, and 6 harvested for yield. Small grain was drilled with a 12-7 drill, 3½ widths.

TABLE 1.—Crops Grown on Blocks M, N, and O, Paulding Farm

Year	Crops on block		
	M	N	O
1914	Clover		
1915	Corn	Clover	Wheat
1916	Oats	Corn	Clover
1917	Wheat	Oats	Corn
1918	Clover	Wheat	Oats
1919	Corn	Clover	Wheat
1920	Oat var.	Corn	Mixed hay
1921	Wheat	Oats	Corn
1922	Clover	Wheat	Oats
1923	Corn	Sweetclover	Wheat
1924	Oats	Corn	Sweetclover
1925	Wheat	Oats	Corn
1926	Sweetclover	Wheat	Oats
1927	Corn	Sweetclover	Wheat
1928	Soybeans	Corn	Clover
1929	Small grain	Soybean var.	Wheat
1930	Wheat	Small grain (Spring)	Corn
1931	Corn	Wheat	Soybeans
1932	Soybeans	Corn	Oats
1933	Oats	Oats	Wheat
1934	Wheat	Sweetclover	Corn
1935	Corn	Wheat	Oats

This plan provided for one plot of each crop each year, but no duplication of rotations—a serious defect in the plan, but made necessary at the time by the small amount of land available and somewhat justified by the exploratory nature of the test.

Rotations A and B were intended to provide the best conditions for soil building and compare pure alfalfa with an alfalfa-grass mixture for this purpose. The plots of continuous alfalfa and continuous bluegrass were put in for observation of their effects on soil structure. Earlier experience on the farm had shown that when bluegrass strips were plowed the structure obtained was perhaps the best seen on the farm.

Rotations C, D, and E were three-year rotations for comparison with the two and four-year rotations. Rotation C compares particularly with A and B; Rotation D compares particularly with Rotations F and G; Rotation E was to study the possibility of introducing soybeans, which were just becoming an important crop in northwestern Ohio when this experiment was planned, into these rotations.

Rotations F, G, and H studied the common corn-oats rotation of the area. Rotations I, J, K, and L were to compare the effects of continuous soybeans and corn on soil structure, and the effect of soybeans for hay on structure with that of soybeans for seed.

For the first few years, no fertilizers were applied to any crops. In an attempt to distinguish structure and fertility effects, the fertilizer schedule in Table 2, for the south halves of the plots only, was established in November 1940, for the 1941 crops and following.

TABLE 2.—Fertilizer Applications, Paulding, Begun November 1940 (South halves of plots only)

Rotation	Fertilizer	Frequency	To be applied
A, B	400 lb./A. 0-20-20	Once per rotation	Broadcast before plowing for corn.
C, D, E	300 lb./A. 0-20-20	Once per rotation	Broadcast before plowing for corn.
F	200 lb./A. 0-20-20	Once per rotation	Broadcast before plowing for corn.
G, H	300 lb./A. $(NH_4)_2SO_4$ 200 lb./A. 0-20-20	Once per rotation	Broadcast and plow down in fall preceding corn.
I, J, K, L	150 lb./A. $(NH_4)_2SO_4$ 100 lb./A. 0-20-20	Annually	Broadcast and plowed down in fall
M	100 lb./A. 0-20-20 for each year since last seeding	Every reseeding	Broadcast before plowing for reseeding.
N	150 lb./A. $(NH_4)_2SO_4$ 100 lb./A. 0-20-20	Annually	Top dress in early spring.

These amounts were changed in 1945 to 150 pounds per acre of 0-20-20 for corn in Rotations A, B, C, D, E, F, G, and H, 150 pounds annually in Rotations I and J, 300 pounds of 20-0-0 annually on Rotations I, J, K, L, and N and before corn (plowed under in the fall) in Rotations D, G, and H. Also beginning with 1945 corn, manure equal to 2/3 the weight of the crops removed was applied to the second-year hay in Rotations A and B before plowing for corn on the **entire** plot, both "unfertilized" and "fertilized" halves.

Despite the amounts of fertilizer applied, differences in appearance and yield between the fertilized and unfertilized halves were slight. Until 1945, corn was the only crop harvested by half plots. In 1947, because of shortage of labor, all crops were harvested fertilized and unfertilized halves together.

A possible source of error in comparisons of the fertilized and unfertilized halves lies in the fact that the tile lines were not uniformly placed in the plots. All attempts to correlate tile line arrangement with yields have failed, but the tile did not affect the plots uniformly.

Since we have data on fertilized crops other than corn only for the years of 1945, 1946, 1948, and 1949, it does not seem worth while to give the data on these crops—there were no large differences between fertilized and unfertilized half plots at any time. Alfalfa, interestingly, gave the most consistent increases, averaging (including alfalfa-brome) all plots for the four years, an increase of 760 pounds per acre. The yields of all the crops, with the yields of fertilized corn for the years for which we have data, are given in Table 3.

The extraordinary effects on that soil of these rotations on the Paulding farm have already been described (8). The four years of the experiment after that paper was published in no wise changed its essential conclusions. The great natural fertility of this soil is emphasized by the failure of reasonably heavy fertilization to give substantial increases in yield when the soil was in good physical condition. The mediocre (though high as a percentage) returns from fertilizer on plots which were in poor physical condition reflect the dominant effects of physical properties of this soil on yields.

The pictures reproduced in Figure 1, taken shortly after a heavy rain, show clearly the destruction of soil structure after 9 years of continuous cropping. Plot 30, Rotation J, looks as if it were lower and ponded, but it is simply that water has stood on the surface instead of being absorbed. The appearance of the corn in four rotations in 1946 is shown in Figure 2. This same general contrast was present throughout the experiment.

TABLE 3.—Rotation Experiment, Paulding County Experiment Farm, 1939-1949. Experiment started in 1936. Half of each plot fertilized in 1941 and thereafter. Crops other than corn, average fertilized and unfertilized.

Rotation	Yield per acre, bushels or pounds											Averages		Percent Highest yield = 100	
	1939	1940	1941	1942	1943	1944	1945	1946	1947[1]	1948	1949	11-yr.	8-yr.	11-yr. av.	8-yr. av.
A.															
Corn, unfertilized	91.5	71.6	35.9	76.3	79.0	55.8	81.7	50.4	62.5	100.8	89.4	72.3	71.2	98	91
Corn, fertilized	----	----	36.8	88.5	90.8	49.5	88.1	53.1	----	93.1	87.6	----	73.4		94
Oats	45.1	82.5	50.9	41.0[5]	22.5	50.9	67.5	56.3	39.1	78.5	53.4	53.4	----	96	
Alfalfa, first year	5500[4]	7450	5400	8900	6520	4650	6050	4750	6400	[6]	9700	6530[2]	----		
Alfalfa, second year	6350[4]	10600	6500	12600	2700	5800	4500	3750	8200	7300	8100[7]	6940	----		
B.															
Corn, unfertilized	88.2	73.2	37.7	94.9	82.2	59.0	77.2	58.6	54.5	90.8	92.2	73.5	74.1	100	95
Corn, fertilized	----	----	41.8	96.7	95.3	59.0	85.8	63.1	----	90.8	94.0	----	78.3		100
Oats	52.8	84.1	53.1	30.6[5]	21.8	43.8	65.0	62.5	42.2	83.0	60.0	54.4	----	97	
Alfalfa-brome first year	5500[4]	7900	5900	8900	6900	5450	5200	5970	7700	[6]	9850	6930[2]	----		
Alfalfa-brome second year	4300[4]	8850	6300	13250	3200	7150	4300	4800	11200	8500	8500[7]	7300	----		
C.															
Corn, unfertilized	89.9	63.2	28.6	80.8	64.0	49.9	76.7	59.0	61.2	52.2	93.1	65.3	63.0	89	80
Corn, fertilized	----	----	33.1	98.5	66.3	56.8	81.3	50.8	----	43.1	79.4	----	63.7		81
Oats	47.2	80.0	67.2	35.2[5]	21.1	28.1	72.5	64.1	36.0	75.5	62.8	53.6	----	96	
Alfalfa	2500[5]	6100	4400	10400	4500	4650	5500	6650	7300	4850	5750	5690[2]	----		

TABLE 3.—Rotation Experiment, Paulding County Experiment Farm, 1939-1949. Experiment started in 1936. Half of each plot fertilized in 1941 and thereafter. Crops other than corn, average fertilized and unfertilized—Continued

Rotation	Yield per acre, bushels or pounds											Averages		Percent Highest yield=100	
	1939	1940	1941	1942	1943	1944	1945	1946	1947[1]	1948	1949	11-yr.	8-yr.	11-yr. av.	8-yr. av.
D.															
Corn, unfertilized	96.0	72.8	36.3	90.4	59.5	52.2	73.5	59.9	70.5	90.8	102.2	73.1	70.6	99	90
Corn, fertilized	----	----	41.8	92.6	59.9	34.0	74.5	55.4	----	90.8	123.5	----	71.6		91
Oats	56.2	79.7	62.5	44.6[3]	23.9	37.5	66.3	65.6	57.9	66.0	53.8	55.8	----	100	
Sweetclover-orchardgrass, cut in June and allowed to remain. Orchardgrass grew up through the hay.															
E.															
Corn, unfertilized	95.4	63.7	33.1	83.5	45.9	42.7	60.4	37.2	53.2	74.9	70.4	60.0	56.0	82	72
Corn, fertilized	----	----	38.6	89.0	60.8	42.2	64.5	63.1	----	68.1	68.1	----	61.8		79
Soybean seed	34.1	5.3	19.6	33.3	28.3	12.3	15.3	8.5	21.1	7.5	30.7	19.6	----	89	
Oats(sweetclover)[2]	66.4	74.4	70.6	56.8	23.1	39.1	24.7	46.9	48.5	49.0	48.4	49.8	----		
F.															
Corn, unfertilized	82.9	68.6	27.2	77.2	64.9	36.3	47.7	37.2	46.6	72.6	61.3	56.6	53.1	77	68
Corn, fertilized	----	----	34.1	82.2	64.9	26.3	59.9	30.0	----	59.0	49.9	----	50.8		65
Oats (sweetclover)[2]	48.6	65.6	72.2	52.4	11.9	31.3	47.5	31.3	21.9	38.0	45.3	42.4	----	76	

TABLE 3.—Rotation Experiment, Paulding County Experiment Farm, 1939-1949. Experiment started in 1936. Half of each plot fertilized in 1941 and thereafter. Crops other than corn, average fertilized and unfertilized—Continued

Rotation	Yield per acre, bushels or pounds											Averages		Percent Highest yield=100	
	1939	1940	1941	1942	1943	1944	1945	1946	1947[1]	1948	1949	11-yr.	8-yr.	11-yr. av.	8-yr. av.
G.															
Corn, unfertilized	73.3	66.1	22.7	66.3	40.0	52.7	52.2	16.8	45.9	72.6	27.2	48.7	43.8	66	56
Corn, fertilized	----	----	34.0	83.5	53.6	30.0	67.6	20.0	----	95.3	61.3	----	55.7		71
Oats	47.3	55.0	72.5	48.1	13.3	20.3	48.8	26.6	31.3	39.0	41.9	40.4	----	72	
(No sweetclover, residues left.)															
H.															
Corn, unfertilized	51.7	55.6	22.7	43.1	33.6	27.7	37.7	14.1	37.9	90.8	36.3	41.0	38.3	56	49
Corn, fertilized	----	----	28.1	86.7	39.5	40.4	51.3	20.9	----	95.3	54.5	----	52.1		67
Oats	40.3	52.2	69.1	44.7	14.1	25.0	40.0	34.4	28.2	29.0	36.9	37.6	----	67	
(No sweetclover, residues removed.)															
I.															
Corn, unfertilized	43.2	36.2	21.8	30.0	16.3	12.7	26.3	8.6	22.6	22.7	15.9	23.3	19.3	32	25
Corn, fertilized	----	----	26.3	38.1	16.8	19.5	37.2	10.0	----	49.9	27.2	----	28.1		36
(Continuous, husked from stalk, stalks left.)															

TABLE 3.—Rotation Experiment, Paulding County Experiment Farm, 1939-1949. Experiment started in 1936. Half of each plot fertilized in 1941 and thereafter. Crops other than corn, average fertilized and unfertilized—Continued

Rotation	Yield per acre, bushels or pounds											Averages		Percent Highest yield=100	
	1939	1940	1941	1942	1943	1944	1945	1946	1947[1]	1948	1949	11-yr.	8-yr.	11-yr. av.	8-yr. av.
J.															
Corn, unfertilized	49.1	35.6	27.2	32.2	20.0	8.2	27.7	5.9	21.3	31.8	15.9	25.0	21.1	34	27
Corn, fertilized	----	----	25.9	38.6	23.6	15.9	48.1	11.8	----	54.5	27.2	----	30.7		39
(Continuous, stalks removed.)															
K															
Soybean hay	6550	7950	3800	8600	4750	4200	6000	4050	4100	4200	6500	5520	----		
(Continuous, taken off.)															
L															
Soybean seed	36.8	5.3	20.9	33.0	24.2	16.7	12.0	10.7	19.5	18 5	18 5	19 6	----		
(Continuous, straw returned.)															
M.															
Alfalfa	No record	3750	[10]	14000	6250	2950	2750[10]	7500	6900	10250	10880	7250[3]	----		
Alfalfa	No record	2650	[10]	13550	6250	2300	2250[10]	6300	6300	9750	11550	6770[3]	----		
(Continuous.)															

TABLE 3.—Rotation Experiment, Paulding County Experiment Farm, 1939-1949. Experiment started in 1936. Half of each plot fertilized in 1941 and thereafter. Crops other than corn, average fertilized and unfertilized—Concluded

Rotation	Yield per acre, bushels or pounds											Averages		Percent: Highest yield=100	
	1939	1940	1941	1942	1943	1944	1945	1946	1947[1]	1948	1949	11-yr.	8-yr.	11-yr. av.	8-yr. av.
N. Bluegrass (Continuous.)	No record	3150	1200	2300	900	2050	800	1100	No record	5550	3900	2330[3]	----		

[1]In 1947, fertilized and unfertilized halves of plots were harvested and weighed together.
[2]10-year average.
[3]9-year average.
[4]Second and third cuttings only.
[5]Badly lodged—reduced the yield.
[6]Seeding failed in 1947, reseeded in oats in 1948.
[7]First-year hay, seeded in 1948.
[8]Third cutting only—not included in average.
[9]Several failures of sweetclover from sweetclover weevil attacks.
[10]Reseded; to Ranger in 1945.

Fig. 1.—Appearance of Paulding plots on May 10, 1944, one day after a heavy rain, showing inadequate drainage on continuous corn plot, above; and adequate drainage on corn-oats-sweetclover plot, below.

Fig. 2.—Corn in Four Rotations at the Paulding County Experiment Farm. August 1946. Upper left, 4-year rotation (C-O-ABr-ABr); upper right, 3-year rotation (C-O-A); lower left, 2-year rotation (C-O(Sw.cl.); lower right, continuous corn.

The Soil Conservation Service took plugs from Rotations B and J in 1948. These plugs were prepared and mounted for use in talks on the necessity for better treatment of Northwestern Ohio clay soils. A photograph of these plugs (Figure 3) shows clearly the difference in structure between the best plot and the poorest plot at that time.

There was no indication that the alfalfa-grass mixture was superior in its effects on corn yields to alfalfa alone. The 11-year average corn yields were within a bushel of each other, although the alfalfa-brome rotation yielded more than the alfalfa rotation in seven of the eleven years. Even the 5-bushel difference in the 8-year average, fertilized, is hardly significant.

The 4-year rotations seemed superior to the 3-year rotation, since the corn in the rotations with two years of alfalfa outyielded that in Rotation C in eight of the eleven years. However, a large share of the difference in final average yields comes from an entirely unbelievable yield of only 52.2 bushels of corn in 1948, which was practically only half the yield in the other rotations. This yield is so completely unreasonable when compared to all the others for that year that it seems that circumstances not connected with the rotation as such must have affected the record. It was hardly a simple weighing error, since the

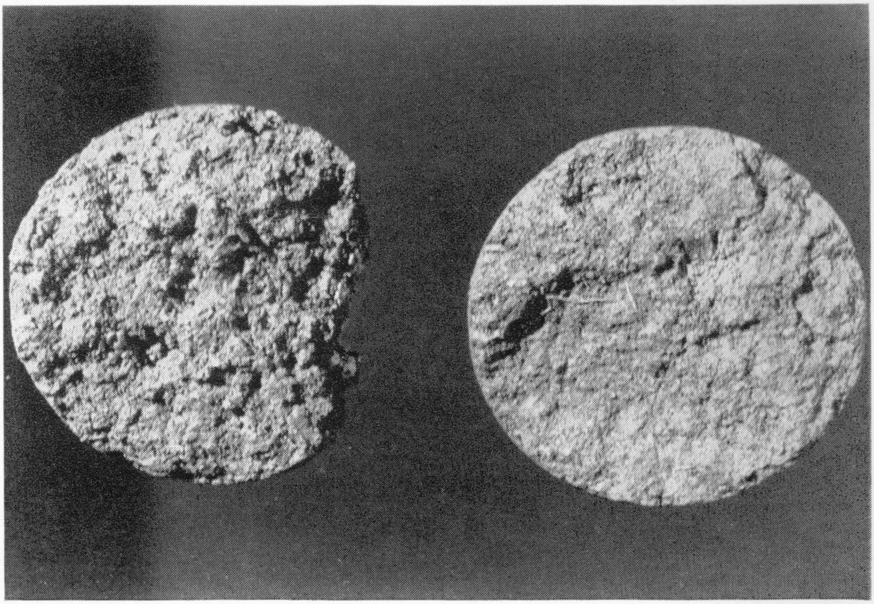

Fig. 3.—Plugs of soil from corn plots on the Paulding farm, 1948. Left, from corn, oats, alfalfa-brome, alfalfa-brome rotation; right, from continuous corn.

two halves of the plot were similar, but not the same, in yield. Local factors of microrelief and drainage affect plots on these soils to an almost unbelievable extent, and are responsible for much of the variability experienced in yields, but the writer believes that this was more probably due to some human error.

Rotation E was like all the other sweetclover rotations here and at Holgate in giving mediocre results during these years. The author discovered for the first time in Ohio the work of the sweetclover weevil on the plots at Holgate in 1943, and in that year and thereafter the weevil reduced the stand of sweetclover so seriously as to greatly reduce the amount of nitrogen available from sweetclover. That this reduction actually was because of the sweetclover weevil is shown by stand counts in the sweetclover for green manure rotation at Holgate, where actual stands were counted before and after the advent of the weevil. In the '30's, before the weevil was present, the average number of sweetclover plants per square yard, as an average of all counts made during that period, was 154; from 1943 to 1946, the average number of plants per square yard was 20. Farmers in the area have largely given up growing sweetclover, because of the difficulty in obtaining stands. Recently it has been shown (12) that it is possible to control sweetclover weevil, so there is no longer any necessary reason for not using this best-of-all leguminous catch crops. It is particular valuable in the Paulding area, as was shown in the '20's.

The corn-oats rotations without sweetclover behaved as in other experiments in Ohio and other states. The yields of both corn and oats are severely reduced but the corn yield was above that with continuous corn. This was especially true with good fertilization.

THE HOLGATE EXPERIMENTS, HENRY COUNTY

The experiments on the Northwestern Experiment Farm at Holgate, in southern Henry County, were conducted on what was called Brookston clay at the time the test was begun, but is now called Hoytville clay. This is one of the most important and productive soils in the Ohio lakebed area. It is described (6, page 8) as follows:

"**Hoytville clay** is a very poorly drained, dark colored soil found on broad upland flats of the Lake Plain of Northwestern Ohio. The dark brownish-gray topsoil is about 8 or 9 inches thick, usually contains from 40 to 45 percent of clay, and is friable and high in organic matter. This layer is underlain with a plastic, gray and brownish-yellow subsoil. The subsoil, containing between 43 and 50 percent of clay, is a little heavier (finer textured) than the topsoil. Below this at depths of 32 to 42 inches is high lime glacial clay till.

"When it is in good tilth, Hoytville clay works well; but it becomes quite hard, cloddy, and difficult to work when poor tilth is caused by excessive grain cropping or by cultivating when wet. Tile drainage is required to remove excess water from the soil. Because of the many cracks and their stability, this soil responds well to tile if good tilth is present. After good drainage has been established, it will grow all crops common to the area. It has the capacity to furnish adequate air and water for good crop growth.

"Generally, this soil contains a good supply of phosphorus and potassium, but it occasionally may need lime."

The Holgate experiment was conducted on the same plots that were used from 1929 to 1938 for a corn fertility experiment in the rotation corn-oats-alfalfa-wheat with a sweetclover catch crop. The summarized yields, given in Table 4, give an idea of the previous yields on this land. This is a highly soil-conserving rotation, so the soil was at least not run-down when these rotations were started.

There were four ranges at Holgate, numbered 100, 200, 300 and 400, respectively, from west to east. The plots in each range were numbered from north to south; thus plot 203 was the third plot from the north in Range 200. The plots numbered with the last two figures the same were directly east-west of each other. The plan was as follows:

Rotation	**Plots**
A. Corn–Oats–Alfalfa–Alfalfa	101, 201, 301, 401
B. Corn–Oats–Alfalfa and orchard, two years	102, 202, 302, 402
C. Corn–Oats–Alfalfa and brome, two years	103, 203, 303, 403
D. Corn–Oats–Alfalfa–Wheat(swcl.)	104, 204, 304, 404
and	108, 208, 308, 408
E. Corn–Corn–Oats–Alfalfa	105, 205, 305, 405
F. Corn–Wheat–Alfalfa-clover-timothy, two years	106, 206, 306, 406
G. Corn–Wheat–Timothy–Timothy	107, 207, 307, 407
H. Corn–Oats–Alfalfa	109, 209, 409
I. Corn–Oats–Medium red clover hay and seed	110, 210, 410
J. Corn–Oats–Alsike clover seed	111, 211, 411
K. Corn–Oats–Sweetclover seed	112, 212, 412
L. Corn–Oats(swcl.) (residues returned)	113, 413
M. Corn–Oats(residues returned)	114, 414
N. Corn–Soybean seed (residues returned)	213, 313
O. Corn–continuous–everything off	309
P. Corn–continuous–stalks left, vetch and yellow sweetclover seeded before July 10	310
R. Continuous soybeans–seed, (residues returned)	312
S. Continuous soybeans–hay, removed	311
T. Continuous bluegrass (N. fertilized, hay removed)	214
U. Continuous bluegrass (No treatment, hay removed)	314

Rotation D continued the rotation on which the plots had been operated since 1929. It was continued as D1 and D2 on Plots 4 and 8. The variation in yield of these plots gives at least that much measure of the possible variation in yield of identically treated plots in this experiment.

All of the Paulding rotations except continuous alfalfa and the 2-year rotation of corn and oats with the residues removed were repeated at Holgate. In addition, rotations B, D, E, F, G, I, and J were new at Holgate.

TABLE 4.—Yields, Corn Fertilizer Experiment, Holgate
Rotation: Corn-Oats-Alfalfa-Wheat(Sweetclover) 1930-38
3 replications of each treatment, except "none", 7 replications
No yields taken in 1933

	Treatment on corn*	Yield per acre			
		Corn 8-yr. av.	Oats 7-yr. av.	Wheat 7-yr. av.	Alfalfa 6-yr. av.
		Bu.	Bu.	Bu.	Bu.
1.	8. None	57.9	53.6	31.8	3890
2.	150 lb. 0-14- 6 hill	59.0	54 6	35.5	4140
3.	150 lb. 2-12- 6 hill	58.0	54.1	33.9	4210
4.	150 lb. 0-14- 6 hill, 200 lb. 0-14-6 BC	59.7	55 5	35.6	4310
5.	150 lb. 0-14- 6 hill	59.4	58.3	35.8	4340
6.	75 lb. 0-14- 6 hill	59.6	56.4	34.1	4070
7.	150 lb. 0-20- 0 hill	59.7	56.5	35.2	4130
9.	150 lb. 0-12-12 hill	60.5	55.2	34.6	4070
10.	150 lb. 0-14- 6† hill	60.8	56.7	34.0	4110
11.	8 tons manure,	59.1	58.5	34.7	4200
12.	8 tons manure, 150 lb. 0-14-6 hill	58.0	57.7	35.3	4350

*Wheat; all treated plots, 300 lb./A. 0-14-6: Oats; Plot 5, 200 lb./A. 0-14-6, others nothing: Alfalfa; residual effects only.

†P_2O_5 carried in Rhums Phosphate.

The report of the project for 1940 says: "The layout has the following objectives:

"1. A comparison of the effect on soil structure of alfalfa on the land 1/4, 1/3, and 1/2 of the time (Rotations E, H, A).

"2. The relative effects on soil structure of fertilized grasses (shallow root systems) versus legumes (deep root systems) and combinations of the two (Rotations G, T and U, and A, H, I, J, K and L, and B, C, and F).

"3. A comparison of a bunch and a sod grass in mixture with alfalfa (Rotations B and C).

"4. A comparison of different important legumes in three-year rotations (Rotations H, I, J, K).

"5. A series of rotations producing effects on soil structure ranging from the worst (Rotations O, P, and R) to probably the best (Rotations A, B, C, D, H, and L).

"6. A study of the effects of soybeans on soil structure on this type (Rotations N, R, and S).

"7. One plot to give some answer to the possibility of sowing legumes in corn to reduce the loss from continuous corn (Rotation P).

"8. In connection with providing a favorable companion crop for timothy, a study of wheat after corn on this soil type (Rotations F and G)."

The rotations were uniformly given the equivalent of 100 pounds per acre per year of 0-14-6, with 400 pounds per acre of ammonium sulfate applied to Rotation T.

Several changes were made in 1946. The basic fertilization was increased to 200 pounds per acre per year of 0-12-12. Common ryegrass was to be sown in the corn in Rotation P, (the vetch and sweetclover had consistently failed under the conditions of this experiment, though successful elsewhere) and 500 pounds per acre of sulfate of ammonia were to be plowed under with the stalks and ryegrass in the spring. In Rotation G, 400 pounds per acre of 20-0-0 were applied to the timothy early each spring, but no nitrogen was plowed under for corn. Through a misunderstanding, this application was not made until 1947. In Rotation K, which had started as corn-oats-sweetclover seed, but in which no seed was ever harvested, orchardgrass was added to the sweetclover, which was cut and removed in June of the second year. The orchardgrass made a heavy sod in the remainder of the year, and 500 pounds per acre of sulfate of ammonia were plowed under with this sod in the fall. All corn plots, except Rotation P, were plowed in the fall.

The general results, as reported in Table 5, were similar to those on the Paulding farm. Alfalfa was as good as the alfalfa-grass mixtures to precede corn, timothy was almost as good. The 3-year rotations definitely were as good as the 4-year. Two years of corn in four reduced the yield of both years slightly. Soybean seed was no better than oats to precede corn. There was a larger response to heavy nitrogen fertilization than at Paulding, but the application was heavier. The results of heavy nitrogen on orchardgrass-sweetclover sod seemed especially favorable, but the economic justification for the rotation as a whole was small. Sweetclover green manure was mediocre, for reasons already explained.

With much higher yields now being obtained on these same soils, the question is bound to arise "Why were not larger corn yields obtained on the best plots?" There is no one answer to this.

The apparent low yields are not due to poor surface drainage, ponding, or similar obvious sources of error. The plots were representative of the areas. At Holgate, the entire plots were harvested for yield, and it was often obvious that the outside rows, exposed to wind, insect migrations and other accidents, were much poorer than the inside rows. A rate of planting corn of 10,000 to 12,000 seeds per acre would reduce the yield of the highest yielding plots. (The rate was not adjusted to prospective yield as it should have been for maximum results.) The year 1947 was one of almost total failure of corn, the highest yield being 26 bushels per acre on Rotation K, with no others above 20. This near-failure severely reduces a four-year average, and there were only five years in which these plots were treated to obtain high yields.

TABLE 5.—Rotation Experiment, Holgate, 1942-1950. Experiment started in 1939

Rotation	Yield per acre, bushels or pounds									Averages			Percent
	1942	1943	1944	1945	1946	1947	1948	1949	1950	1942 to 1946	1947 to 1950	1942 to 1950	1942 to 1950 Highest=100
A.													
Corn	72.2	29.5	48.4	45.3	66.4	15.7	82.3	77.0	109.3	52.4	71.1	60.7	96
Oats	71.4	20.6	47.5	84.6	58.8	25.4	44.2	33.8	34.8	56.6	34.6	46.8	92
Alfalfa	3750	6050	3160	7050	4570	2830	9360	4110	5880	4920	5540	5200	75
Alfalfa	7500	4970	2810	5400	6020	3970	4230	8070	4710	5340	5240	5300	76
B.													
Corn	73.2	35.5	54.3	53.3	59.6	17.5	98.6	68.2	109.7	55.2	73.5	63 3	100
Oats	55.9	29.1	52.2	80.8	59.7	23.5	63.9	40.4	39.5	55.6	41.8	49.4	97
Alfalfa-orchardgrass	3980	7620	4700	6270	5300	3680	8580	5580	6180	5570	6000	5770	83
Alfalfa-orchardgrass	8610	7070	4810	8070	6470	6250	5700	9720	6060	7010	6930	6970	100
C.													
Corn	73.2	30.3	54.7	54.5	60.1	15.9	95.6	78.7	106.3	54.6	74.1	63.3	100
Oats	55.0	23.0	50.8	78.0	64.4	29.1	56.4	44.2	51.7	54.0	45.3	50.2	99
Alfalfa-brome	4220	7440	5070	8280	3760	3900	9420	6750	6090	5750	6540	6100	88
Alfalfa-brome	7200	6550	5590	8520	7930	6230	5550	9060	5610	7160	6610	6920	99
D1.													
Corn	69.0	36.5	45.8	57.1	52.6	20.0	82.3	76.6	82.9	52.2	65.2	58.1	92
Oats	68.7	23.4	53.2	73.3	66.7	23.5	74.3	36.7	38.5	57.1	43.2	50.9	100
Alfalfa	3660	5590	3940	6690	5780	3690	8760	6270	5280	5130	6000	5520	79
Wheat(swcl)	30.0[2]	32.0[2]	28.0[2]	35.5[2]	39.8	25.5	26.0	34.0	40.5	33.1	31.5	32.4	93

TABLE 5.—Rotation Experiment, Holgate, 1942-1950. Experiment started in 1939—Continued

Rotation	Yield per acre, bushels or pounds									Averages			Percent
	1942	1943	1944	1945	1946	1947	1948	1949	1950	1942 to 1946	1947 to 1950	1942 to 1950	1942 to 1950 Highest=100
D2.													
Corn	62.8	27.0	40.6	46.1	48.9	20.4	87.4	84.6	92.9	45.1	71.3	56.7	90
Oats	65.0	30.0	39.4	57.3	50.8	20.7	52.6	41.4	39.5	48.5	38.5	44.1	87
Alfalfa	3950	5500	2850	5580	4070	2480	7530	5040	4290	4390	4840	4590	66
Wheat(swcl)	30.0	32.0	28.0	35.5	45.5	35.5	16.0	48.0	43.5	34.2	35.7	34.9	100
E.													
Corn	64.9	26.0	39.3	53.0[1]	47.2	11.6	69.8	85.0	89.6	46.1	64.0	54.0	85
Corn	69.0	25.8	42.0	53.0	47.2[1]	20.0	83.6	58.6	74.5	47.4	59.2	52.6	83
Oats	66.9	24.4	43.7	68.6	57.3	26.3	69.6	41.4	37.6	52.2	43.7	48.4	95
Alfalfa	3840	7270	3220	7260	4910	2900	7620	6060	5670	5300	5560	5420	78
F.													
Corn	65.9	22.0	54.0	42.1	68.4	19.6	77.1	75.8	104.6	50.5	69.3	58.8	93
Wheat	27.3	22.5	32.8	43.0	33 8	20.8	21.5	38.5	25.5	31.9	26.6	29.5	85
Alfalfa-clover-timothy	2610	8130	5490	9660	6810	4290	7830	6600	4200	6540	5730	6180	89
Alfalfa-clover-timothy	6800	6880	3640	9090	8420	4450	4110	8250	6240	6970	5760	6430	92
G.													
Corn	62.8	27.6	49.4	42.1	50.2	17.6	75.0	76.2	92.5	46.4	65.3	54.8*	
Wheat	30.7	21.3	30.2	36.0	36.0	20.8[3]	23.0	38.0	24.0	30.8	26.4	28.8	83
Timothy	3460	6910	4550	3930	4100	5290	5700	3690	4050	4590	4680	4630	
Timothy	5860	6680	4380	5550	4570	5290	4800	7770	5250	5410	5780	5570	

(Eighty pounds per acre nitrogen applied to both first- and second-year timothy, 1947-1950.)

TABLE 5.—Rotation Experiment, Holgate, 1942-1950. Experiment started in 1939—Continued

Rotation	Yield per acre, bushels or pounds									Averages			Percent
	1942	1943	1944	1945	1946	1947	1948	1949	1950	1942 to 1946	1947 to 1950	1942 to 1950	1942 to 1950 Highest=100
H.													
Corn	72.2	31.0	53.6	50.7	50.9	10.5	71.6	82.0	112.2	51.7	69.1	59.4	94
Oats	52.2	29.5	35.2	75.2	55.5	20.7	45.1	32.9	47.0	49.5	36.4	43.7	86
Alfalfa	2400	7130	3350	5610	5640	2470	5820	4320	2550	4830	3790	4370	63
I.													
Corn	70.1	32.8	53.7	52.6	55.3	15.4	83.1	78.3	109.3	52.9	71.4	61.2	97
Oats	54.0	27.2	39.0	74.3	60.2	24.4	54.5	39.5	45.1	50.9	40.9	46.5	91
Medium red clover	----	4110	2450	6240	5280	4540	3000	6120	960	4520	3660	4090	
(Hay and seed. Seed seldom harvested. Hay one cutting only.)													
J.													
Corn	63.3	41.5	48.6	48.3	58.3	13.5	83.1	75.8	116.4	52.0	72.2	61.0	96
Oats	55.0	24.8	40.8	86.5	51.2	25.4	53.6	41.4	40.4	51.7	40.2	46.6	92
Alsike clover seed. (Seed harvested only one year. Growth usually removed.)													
K.													
Corn	66.4	26.2	50.4	47.9	56.0	25.9	80.6	97.1	123.5	49.4	81.8	63.8*	
Oats	41.2	29.1	42.8	73.3	54.5	24.4	57.3	37.6	46.1	48.2	41.3	45.1	87
Sweetclover-orchardgrass. (Cut in June, taken off, orchardgrass not cut thereafter. 100 pounds per acre nitrogen plowed under, 1947-1950.)													

TABLE 5.—Rotation Experiment, Holgate, 1942-1950. Experiment started in 1939—Continued

Rotation	Yield per acre, bushels or pounds									Averages			Percent
	1942	1943	1944	1945	1946	1947	1948	1949	1950	1942 to 1946	1947 to 1950	1942 to 1950	1942 to 1950 Highest=100
L.													
Corn	60.1	25.0	48.0	50.9	48.5	16.3	82.7	59.4	103.4	46.5	65.6	55.0	87
Oats(Sweetclover)	75.1	14.5	45.6	72.4	59.2	16.9	57.3	21 6	32.9	53.3	32.2	43.9	86
(Residues returned.)													
M.													
Corn	57.5	28.5	34.1	48.4	30.9	11.8	57.8	44.4	46.5	39.9	40.1	40.0	63
Oats	59.5	22.5	39.9	56.4	42.3	18.8	48.9	22.6	37.6	44.1	32.0	38.7	76
(No legume sown, residues returned.)													
N.													
Corn	57.5	18.5	25.4	45.4	41.1	9.8	66.8	51.5	58.2	37.6	46.6	41.6	66
Soybean seed	22.2	20.8	13.2	17.3	9.8	11.9	23.5	26.4	30.3	16 7	23.0	19.5	
(Residues returned.)													
O.													
Corn	58.0	9.7	26.9	40.5	39.2	8.6	53.6	28.9	36.8	34.9	32.0	33.6	53
(Continuous, everything off.)													
P.													
Corn	52.8	12.1	29.7	44.9	41.1	10.7	74.6	60.3	72.0	36.1	54 4	44.2*	
(Continuous, stalks left. 100 pounds per acre nitrogen plowed under, 1947-1950.)													

TABLE 5.—Rotation Experiment, Holgate, 1942-1950. Experiment started in 1939—Concluded

Rotation	Yield per acre, bushels or pounds									Averages			Percent
	1942	1943	1944	1945	1946	1947	1948	1949	1950	1942 to 1946	1947 to 1950	1942 to 1950	1942 to 1950 Highest=100
R.													
Soybean seed (Continuous, residues returned.)	19.3	25.3	14.0	17.1	12.9	11.5	23.5	25.4	25.4	17.7	21.4	19.4	
S.													
Soybean hay (Continuous, removed.)	2200	3420	2920	2790	6090	4240	3330	6420	4370	3480	4590	3980	
T.													
Bluegrass (Nitrogen fertilized, hay removed.)	3250	4310	2900	2280	3510	8780	2220	2580	2010	3250	3900	3540	
U.													
Bluegrass (No treatment, hay removed.)	2280	2590	760	2310	1810	2320	690	1290	690	1950	1250	1640	

[1]Through error, alfalfa not plowed for corn in 1945. Corn yield estimated at yield of other corn plot in rotation.
[2]Bird damage; yield estimated from Rotation D2.
[3]Bird damage; yield estimated from Rotation F.
[4]Eight-year average.

THE MADISON COUNTY EXPERIMENTS

The Madison County experiments were carried out on soils of the Miami catena on the Madison County Experiment Farm, located a few miles west of London. The area was very non-uniform (See soils map, Fig. 4) but was, nevertheless, unusually uniform for these soils. The soils in the experimental area are described (7) as follows:

"**Celina silt loam** is a light colored moderately well drained soil found on gently rolling topography and developed from calcareous glacial till. The grayish-brown silt loam topsoil is 8 to 10 inches thick

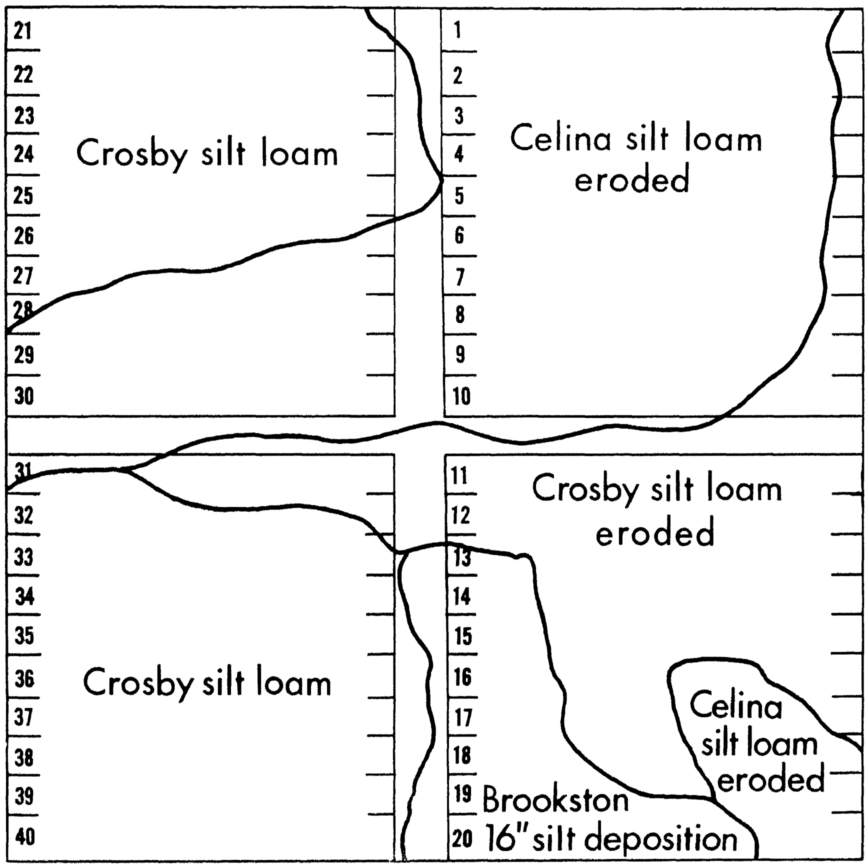

Fig. 4.—Soils map of the rotation plots on the Madison County Experiment Farm.

if no erosion has occurred. The yellowish-brown clay to clay loam subsoil extends to a depth of 28 inches with gray streaks appearing at 16 or 18 inches. Below 28 inches is calcareous glacial till. The productivity of this soil is greatly impaired when it becomes eroded.

"**Crosby silt loam** is a light colored, somewhat poorly drained soil found on gently sloping topography and developed from glacial till. The brownish gray silt loam topsoil is 8 to 10 inches thick. The yellow and gray clay loam subsoil extends to 28 inches. Under this is the calcareous glacial till.

"This soil warms up slowly in the spring because the drainage is naturally slow. Because of the tight compact subsoil, water and air move slowly through the subsoil, root growth is restricted, and tile is needed. Crops on this land are likely to suffer from lack of usable moisture during dry weather as well as from too much water in wet seasons.

"**Brookston silty clay loam** is a dark colored, very poorly drained soil found in depressional areas. The black silty clay loam surface is 12 to 14 inches deep and underlain by gray and yellow silty clay loam subsoil which is somewhat heavier than the surface soil and extends to a depth of 40 inches or more. Beneath the subsoil is the calcareous loam glacial till. Drainage is necessary, but tile can be spaced more widely than in the Crosby silt loam.

"**Brookston silt loam** is similar to above except for a smaller amount of clay in the surface, thus making it somewhat easier to manage."

We do not have a detailed past history of the area, but it had been part of the farm for over 20 years, and had been well treated. There were 40 E-W plots, 27′ × 115′ over all, including borders, in two tiers, the east tier numbered 1 to 20, N-S, and the west tier 21 to 40. Plot 21 is end to end with Plot 1, with a 25′ roadway between the tiers, and between Plots 10 and 11, and 30 and 31.

The plan of the rotations and the fertilizer treatments at the beginning are given in Table 6. The "hay" was an alfalfa-red clover-timothy mixture. The plots were laid out in the summer of 1940, in time for wheat seeding, so that all crops except hay were harvested in 1941. 1944 was the first year of one full round of all rotations and the 1941-1943 data are not reported. The first year corn (which should have been uniform) made 65 to 88 bushels per acre, averaging 77 bushels.

In this plan, 5 cropping systems were duplicated, in order to have at least some measure of variability between identically treated plots. The greatest contrast was between Plot 20, almost all Brookston and Plot 35, all Crosby silt loam. Plot 20 was subject to flooding, however, and in three seasons, Plot 35 outyielded it.

Grain farming is important in Madison County, and these rotations were laid out to study grain farming, and especially the place of soybeans, then a new crop, in the rotation. Only Rotations O and P would be classed as soil-conserving by Ohio standards.

At this time, there were some who felt that it would be profitable to precede soybeans with a sweetclover catch crop. To answer this question decisively, Rotations I, J, M, and N have this crop sequence, which is contrasted with soybeans after corn in Rotations E, F, K, and L. The other rotations are similar to those on the other farms, except the exhaustive cash crop Rotation R.

TABLE 6.—Rotations at the Madison County Experiment Farm Started fall 1940

	Rotation	Plots	Pounds 0-14-7 fertilizer per acre		
			Corn (Hill)	Soybeans (Drilled)	Wheat (Drilled)
A.	Continuous corn	34	150		
B.	Continuous corn (vetch and yellow sweetclover)	35	150		
C.	Duplicate of "B"	20	150*		
D.	Continuous soybeans	36		150	
E.	Corn-soybeans	1, 4	150	150	
F.	Corn-soybeans	37, 39	150	150	
G.	Corn-soybean hay	2, 5	150	150	
H.	Corn-wheat(sweetclover)	3, 6	150		150
I.	Soybeans-wheat(sweetclover)	7, 27			300
J.	Soybeans-wheat(sweetclover)	38, 40			300
K.	Corn-soybeans-wheat(sweetclover)	21, 23, 25	150		300
L.	Corn-soybeans-wheat(sweetclover)	14, 16, 18	150		300
M.	Corn-wheat(sweetclover)-soybeans	22, 24, 26	150		300
N.	Corn-wheat(sweetclover)-soybeans	15, 17, 19	150		300
O.	Corn-soybeans-wheat-hay	8, 11, 28, 31	150	150	300
P.	Corn-wheat-hay-hay	9, 12, 29, 32	150		300†
R.	Corn - wheat(sweetclover) - corn-soybeans	10, 13, 30, 33	150		300

*Drill 150# per acre **additional** BC just before corn planting.

†Drill 150# per acre **additional** when drilling second half of split legume seeding.

As at Northwestern, several changes were made in 1946. Vetch and yellow sweetclover were dropped and ryegrass substituted in Rotations B and C, and 100 pounds per acre of nitrogen were plowed under with the stalks and whatever ryegrass was present in the spring. (It often failed, and was not important, in fact.) The basic fertilizer rate was increased to 300 pounds per acre per year of 0-12-12. Soybeans, which had been drilled solid, were sown in 38″ rows and cultivated to control weeds (except the soybean hay plots).

Also in 1946, Dr. R. E. Yoder, then Head of the department, wanted to experiment somewhat conclusively with fertilizing soybeans with nitrogen and suggested that this rotation series be used. Soybeans build an enormous amount of nitrogen into their seeds in a rather short time and it seemed quite reasonable that extra nitrogen, if applied about flowering time to be available for this grand period of growth, might increase the yield. Accordingly, in the four years 1946 to 1949, the soybeans in Rotations J and N were side-dressed as they came in bloom with 150 pounds per acre of ammonium nitrate and those in Rotations E and K were side-dressed with 300 pounds per acre of ammonium nitrate. The results given in Table 7 indicate conclusively that under these conditions there was no advantage in side-dressing soybeans with nitrogen. There was at times a considerable carry-over effect on wheat. The plots treated with ammonium nitrate gave an average increase for the four years of over four bushels per acre of wheat.

In 1953, following a failure of alfalfa in wheat and feeling that it was desirable to get some information on oats as well, oats were substituted for wheat in Rotation P. Oats are, however, not a usual crop in Madison County.

The data for the Madison County rotations given in Tables 8 and 9 are averaged by two periods. The first period gives the results through 1952, and the second for the five-year period 1953 to 1957, reflecting the results after the rotations had been established for some time. Table 9 averages the yields of corn, soybeans, and wheat following different crops or in different cropping systems. Table 10 gives the yields for the individual rotations by years.

In most respects the order of yields was very similar to that at Paulding and Holgate for similar rotations. Percentage-wise neither continuous corn nor continuous soybeans reduced the yields as much here as on the lakebed soils—presumably a reflection of the better

TABLE 7.—Side-dressing Soybeans with Ammonium Nitrate Madison County Experiment Farm, Rotation Experiment

Rotations and treatment	Yield per acre, bushels				
	1946	1947	1948	1949	Average
J—150 lb./A. ammonium nitrate	24.7	17.1	16.9	28.0	21.7
I—Untreated	19.4	21.4	17.3	29.5	21.9
N—150 lb./A. ammonium nitrate	25.2	21.9	18.2	32.8	24.5
M—Untreated	23.7	23.4	20.7	33.3	25.3
Av. 150 lb./A. ammonium nitrate	25.0	19.5	17.6	30.4	23.1
Av. Untreated	21.6	22.4	19.0	31.4	23.6
E—300 lb./A. ammonium nitrate	23.4	15.6	19.4	32.1	22.7
F—Untreated	21.3	18.1	17.0	26.1	20.6
K—300 lb./A. ammonium nitrate	24.3	18.4	20.7	34.8	24.6
L—Untreated	22.4	24.6	15.9	33.9	24.2
Av. 300 lb./A. ammonium nitrate	24.0	17.0	20.1	33.5	23.7
Av. Untreated	21.8	21.4	16.4	30.0	22.4
Av. both rates	24.5	18.3	18.9	32.0	23.4
Av. untreated	21.7	21.9	17.8	30.7	23.0

physical nature of these silt loam soils. Heavy nitrogen on continuous corn produced very worthwhile yields of corn, but again much less than rotations including sod crops produced. It was quite obvious, however, that if one does not wish to grow the sod crops, a respectable substitute can be produced by plowing under large amounts of nitrogen with the crop residues (Fig. 5).

There was no advantage in corn yield for two years of hay in four over one year of hay in four. Corn after a sweetclover catch crop definitely ranked next to the full-year sod crops. Good stands of sweetclover have been obtained regularly at Madison throughout the period.

Unlike in the lakebed soils, corn was increased in yield after soybeans as hay or seed. In fact, corn after soybeans with no additional nitrogen has been a close competitor for continuous corn with one hundred pounds of nitrogen plowed under. The yields were not significantly different.

Fig. 5.—The 17th continuous crop of corn on Plot 35, Madison County Experiment Farm, Crosby silt loam, 100 pounds nitrogen per acre for the last 11 years, all residues returned.

TABLE 8.—Rotation Experiment, Madison County Experiment Farm Started 1941. Fertilized 300 lb./A. 0-12-12 per year on all plots

Rotation	Crops	Average yield per acre, bushels or pounds		
		1944 to 1952	1953 to 1957	1944 to 1957
A.	Corn, continuous	42.6	43.7	43.0
B.	Corn, continuous	49.9	61.9	*
	Common ryegrass sown at last cultivation. 100 lb./A. of N plowed under in spring, after 1947.			
C.	Duplicate of "B"	60.1	71.9	*
B. and C.	Corn, continuous, high nitrogen	55.0	66.9	*
D.	Soybeans	16.9	19.4	17.8
E.	Corn	60.0	56.6	58.8
	Soybeans	21.2	20.1	20.8
F.	Corn	51.9	54.7	52.9
	Soybeans	20.2	21.2	20.6
E. and F.	Corn	56 0	55.6	55.8
	Soybeans	20.6	20.6	20.6
G.	Corn	60.4	68.5	63.3
	Soybean hay	3410[7]	4280[4]	3730[11]
H.	Corn	65.1	79.1	70.1
	Wheat(swcl)	24 6	28.4	26.0
I.	Wheat(swcl)	31.4	37.2	33.5
	Soybeans	21.4	22.9	22.0
J.	Wheat(swcl)	30.4	33.6	31.6
	Soybeans	20.2	23.3	21.3
I. and J.	Wheat(swcl)	30.9	35.4	32.6
	Soybeans	20.8	23.1	21.6
K.	Corn	67.8	74.0	70.0
	Soybeans	22.8	25.9	23.9
	Wheat(swcl)	30.2	34.7	31.8
L.	Corn	62.7	75.4	67.2
	Soybeans	23.4	26.0	24.3
	Wheat(swcl)	27.6	30.0	28.4
K. and L.	Corn	65.2	74.7	68.6
	Soybeans	23.1	26.0	24.1
	Wheat(swcl)	28.9	32.4	30.1

TABLE 8.—Rotation Experiment, Madison County Experiment Farm Started 1941. Fertilized 300 lb./A. 0-12-12 per year on all plots.—Continued

Rotation	Crops	Average yield per acre, bushels or pounds 1944 to 1952	1953 to 1957	1944 to 1957
M.	Corn	65.3	76.8	69.4
	Wheat(swcl)	22.4	20.3	21.7
	Soybeans	23.2	23.4	23.2
N.	Corn	63.5	68.7	65.4
	Wheat(swcl)	20.1	18.5	19.6
	Soybeans	23.1	25.8	24.1
M. and N.	Corn	64.4	72.8	67.4
	Wheat (swcl)	21.3	19.4	20.6
	Soybeans	23.1	24.6	23.7
O.	Corn	76.3	85.8	79.7
	Soybeans	22.3	26.8[4]	23.7
	Wheat	31.9	33.7	32.6
	Hay	6780[8]	8780	7550[13]
P.	Corn	77.2	84.6	79.8
	Wheat or	33.2		*
	Oats		76.8	*
	Hay	6990[8]	9400	7920[13]
	Hay	7390	9100	8000
R.	Corn (1)	65.7	63.9	65.1
	Wheat(swcl)	23.3	21.5	22.6
	Corn (2)	68.3	76.9	71.4
	Soybeans	21.4	26.8	23.3

*14-year average not significant because of change of plan.

[4, 7, 8, 11, 13] Number of years averaged; records missing for various reasons.

Continuous soybeans were inferior to soybeans in rotation, as was not true in the two comparisons in Northwestern Ohio. A sod crop in the rotation produced slightly but hardly significantly more soybeans than following corn without a sod crop. Soybeans after sweetclover

TABLE 9.—Madison County Experiment Farm. Summary, average yields of corn, soybeans and wheat under different cropping systems.

Crops	Rotations	Yield per acre			Highest yield = 100		
		9 years 1944-52	5 years 1953-57	14 years 1944-57	9 years 1944-52	5 years 1953-57	14 years 1944-52
		Bu.	Bu.	Bu.	Pct.	Pct.	Pct.
Continuous corn, no nitrogen fertilizer	A	42.6	43.7	43.0	55	51	54
Continuous corn, catch crop, plus 100 pounds nitrogen per acre after 1946	B, C	55.0	66.9		71	78	
Corn after soybeans	E, F, G, M, N and R(1st)	61.1	64.9	62.5	79	76	78
Corn after sweetclover catch crop	H, K, L and R(2nd)	66.0	76.3	69.7	85	89	87
Corn after one year of mixed hay	O	76.3	85.8	79.7	99	100	100
Corn after two years of mixed hay	P	77.2	84.6	79.8	100	99	100
Continuous soybean seed	D	16.9	19.4	17.8	76	72	75
Soybeans after corn, no sod crop in rotation	E, F, K, L and R	21.8	24.0	22.6	98	90	95
Soybeans after corn, sod crop in rotation	O	22.3	26.8	23.7	100	100	100
Soybeans after sweetclover plowed under	I, J, M and N	22.0	23.8	22.6	99	89	95
Wheat after corn, no sod crop	H, M, N and R	22.6	22.2	22.5	68	65	69
Wheat after corn, sod crop in rotation	P	33.2			100		
Wheat after soybeans, no sod crop	I, J, K, L	29.9*	33.9	31.3	90	100	96
Wheat after soybeans, sod crop in rotation	O	31.9	33.7	32.6	96	99	100

*This average was apparently 1.0 bushel higher than it would otherwise have been because of the carryover effect of the nitrogen applied to the soybeans in 1946-1949.

TABLE 10.—Rotation Experiment, Madison County Experiment Farm. Started 1941. Fertilized 300 pounds per acre 0-12-12 per year on all plots

Rotation	Yield per acre, bushels or pounds													
	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957
A. Corn	19.4	45.8	41.5	13.5	52.7	65.0	65.8	31.6	48.4	34.2	44.2	49.1	50.5	40.3
B. Corn	12.1	48.0	50.5	14.9	53.9	83.0	85.7	47.8	53.1	46.5	80.0	51.5	60.6	71.1
Common ryegrass sown at last cultivation. 100 pounds per acre of nitrogen plowed under in spring, 1946 and following.														
C. Duplicate of "B"	25.4	42.7	50.5	23.3	63.9	91.2	105.0	59.5	79.4	57.4	98.7	60.9	83.4	59.1
D. Soybeans	10.3	8.6	16 6	15.0	12.5	25.3	17.2	17.2	29.7	22.4	19.9	19.7	12.2	22.9
E. Corn	29.1	57.9	63.1	56.6	52.7	94.9	79.4	52.9	53.5	50.8	61.5	52.2	56.5	61.9
Soybeans	11.5	10.3	23.4	15.6	19.4	32.1	24.4	17.7	36.0	24.9	16.8	24.3	11.2	23.4
F. Corn	14.4	60.8	48.7	48.8	45.7	86.1	68.6	46.9	47.2	46.9	61.5[1]	58.1	48.4	58.5
Soybeans	14.7	11.5	21.3	18.1	17.0	26.1	22.0	18.1	33.3	23.1	27.7	19.4	15.9	20.1
G. Corn	26.7	59.4	64.9	55.0	43.8	85.3	82.1	58.6	58.2	53.7	81.6	62.6	78.1	66.3
Soybean hay	3370	4280	2950	2380	2240	3330	26.4[2]	17.7[2]	5320	3720	4560	22.9[2]	6200	2660
H. Corn	17.2	70.5	58.2	53.2	63.1	94.5	88.0	67.7	73.2	61.8	86.7	80.4	84.1	82.3
Wheat(swcl)	23.5	31.6	28.5	27.8	26.1	27.5	18.5	7.6	30.5	28.8	21.0	35.1	32.6	24.3
I. Wheat(swcl)	26.2	35.2	30.4	34.9	38.7	33.2	26.2	16.2	42.0	35.7	34.1	47.9	34.6	33.7
Soybeans	7.8	6.0	24.7	21.4	17.3	29.5	27.0	18.6	40.7	27.2	25.3	22.0	14.0	26.2
J. Wheat(swcl)	24.2	33.1	28.8	27.0	36.8	32.3	34.5	17.7	39.5	36.2	33.7	42.1	22.1	34.1
Soybeans	12.5	7.9	19.4	17.1	16.9	28.0	23.3	18.4	38.3	23.9	29.2	18.6	16.8	28.1
K. Corn	26.9	67.2	81.2	65.4	63.9	92.2	81.2	62.6	69.8	75.8	77.0	84.6	59.2	72.4
Soybeans	15.8	9.6	24.3	18.4	20.7	34.8	26.4	17.7	37.3	32.3	25.0	24.8	17.8	29.5
Wheat(swcl)	27.1	27.5	31.6	32.1	35.2	35.2	36.8	13.5	32.5	30.5	33.7	47.3	31.6	30.4
L. Corn	13.7	66.4	65.8	45.5	59.4	95.7	78.5	64.9	74.3	72.5	85.2	71.3	68.6	79.4
Soybeans	14.7	11.3	22.4	24.6	15.9	33.9	26.6	21.7	39.8	30.3	33.2	22.9	17.8	25.7
Wheat(swcl)	22.1	25.6	24.4	26.2	30.7	33.0	29.7	16.2	40.2	28.8	28.5	39.2	23.6	29.9

TABLE 10.—Rotation Experiment, Madison County Experiment Farm. Started 1941. Fertilized 300 pounds per acre 0-12-12 per year on all plots—Continued

Rotation		Yield per acre[1], bushels or pounds													
		1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957
M.	Corn	32.2	57.9	66.7	65.8	57.7	94.6	96.0	52.3	64.5	84.8	75.3	76.9	84.1	62.7
	Wheat(swcl)	22.0	25.4	25.8	23.4	32.8	22.9	16.2	8.8	24.3	17.4	19.2	22.8	25.3	16.8
	Soybeans	13.8	7.3	25.2	23.4	20.7	33.3	25.0	21.9	38.0	28.9	23.5	19.0	14.5	30.9
N.	Corn	19.6	60.1	51.7	51.4	62.2	93.8	90.9	59.5	82.5	57.8	66.2	72.4	72.0	75.2
	Wheat(swcl)	20.0	26.6	18.5	20.3	26.4	20.7	15.2	10.4	23.2	22.5	13.8	22.8	21.0	12.6
	Soybeans	15.0	10.0	23.7	21.9	18.2	32.8	26.4	21.4	38.3	28.8	34.4	21.8	16.4	27.6
O.	Corn	29.9	64.9	77.6	64.6	77.7	102.4	104.6	58.6	106.5	73.0	92.0	74.8	101.6	87.8
	Soybeans	10.3	11.6	22.9	22.6	14.3	31.2	25.3	21.7	40.7	35.1	30.5	26.7	15.0	[5]
	Wheat	30.0	29.0	30.7	33.1	38.8	32.8	35.6	17.2	40.0	34.7	31.6	43.8	32.6	26.0
	Hay	4840	7930	6730[3]	6730[3]	5020[3]	[4]	5960	5680	11340	11200	7780	6340	10440	8200
P.	Corn	34.6	67.7	74.7	65.8	84.8	98.1	94.5	63.1	111.6	71.9	100.2	71.7	96.2	83.0
	Wheat	29.5	32.7	35.2	30.5	42.9	37.4	30.4	13.1	47.0					
	Oats										85.3	87.7	79.1	68 8	59.2
	Hay	5470	6320	6870	8410[3]	5230[3]	[4]	6810	5470	11340	10420	8840	4500	10100	13140
	Hay	4630	10460	8480	5260	5250[3]	8900	7090[4]	4840	11620	10840	10300	6080	10500	7740
R.	Corn	32.5	57.5	71.7	63.1	69.5	94.7	91.6	50.5	60.6	52.3	73.5	63.3	53.8	76.6
	Wheat(swcl)	21.8	29.2	25.3	27.5	25.0	24.4	23.2	11.3	21.8	21.6	14.7	30.4	22.1	18.5
	Corn	39.0	69.5	64.0	62.1	68.5	95.3	83.0	53.2	80.0	79.5	84.6	72.4	55.2	92.7
	Soybeans	8.7	9.6	19.0	21.8	16.1	31.9	22.7	26.0	36.6	31.4	25.8	27.4	16.8	32.7

[1]Planted to soybeans by error: yield estimated from rotation E.
[2]Seed.
[3]Two cuttings only.
[4]1948 seeding in wheat failed. Rotation P resown in oats in 1949.
[5]Not planted.

yielded identically the same as soybeans after corn. Sweetclover increased corn yields, and wheat after soybeans was much better than wheat after corn, so if one is growing corn, soybeans, and wheat with a sweetclover catch crop, they should be grown in that order. Wheat also showed a response to a sod crop in the rotation, the advantage in wheat following soybeans being about a bushel per acre and in wheat following corn about 9 bushels. The gain for wheat after soybeans over wheat after corn was about 9 bushels. Presumably, these are largely nitrogen relations, and could have been altered by using more nitrogen on the wheat.

When it was decided that the Madison County Experiment Farm was to be given up late in 1957, attempts were made to obtain some data on the nitrogen and organic content and physical condition of the plots. Nitrogen was also determined in a few samples taken in March of 1956. The author is indebted to his colleagues, Dr. George S. Taylor, Dr. J. L. Mortensen, and their assistants for taking these samples and making the determinations on them. The data are given in Table 11.

The correlation between the nitrogen in the corn leaves in August, the treatment of the soil, and the ultimate yield of the plots was almost remarkable. The only exception was Rotation C, the continuous corn with 100 pounds of nitrogen plowed under on Brookston soil; this could have been expected to be one of the very highest samples, and it was very low. This plot was flooded in 1957, water standing on it for some days, which probably took considerable nitrogen out of the soil. The corn was stunted so that it did not recover all season. It yielded twelve bushels less than Rotation B in 1957, although as a 14-year average it yielded 10 bushels more.

The figures for nitrogen and organic carbon tended to vary with soil type more than with the treatment. Rotations A and B, which were adjacent and originally quite uniform, showed 0.02 percentage points more nitrogen and 0.12 percentage points more organic carbon in B than in A. This may be significant, though it was not statistically so. Rotation D, which lies on the other side of B, was similar to A, which also suggests significance in the nitrogen and carbon figures. The aggregation of the soil was not increased by the high nitrogen treatment.

TABLE 11.—Effects of Rotations in Madison County Experiments

Crops on soil at or preceding sampling	Rotation	Nitrogen in corn leaves August 1957	Nitrogen in soil: March 1956	Nitrogen in soil: August 1957	August, 1957: Organic carbon in soil	August, 1957: Aggregation >2 mm	August, 1957: Aggregation >0.25 mm
		Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
Corn, continuous, no nitrogen	A	0.93	0.113	0.096	1.51	8.8	26.4
Corn, continuous, 100 lb. nitrogen, Crosby soil	B	1.92	0.131	0 115	1.63	7.4	28.1
Corn, continuous, 100 lb. nitrogen, Brookston soil	C	1.32	0.201	0.168	3.31	10.7	39.1
Corn after soybeans	E, F, G, M, N, R(1)	1.08	0.102	0.100	1.33	11.6	32.1
Corn after sweetclover (catch crop)	H, R, L, R(2)	1.56	0.121	0.120	1.33	13.2	39.1
Corn after one year hay	O	1.70	0.146	0.122	1.26	11.2	32 2
Corn after two years hay	P	2.08	0.150	0 134	1.51	23.4	53.6
Soybeans, continuous	D		0.102	0.096	1.49	7.3	33.9
Soybeans after corn, no sod cop in rotation	E, F, K, L, R			0.112	1.18	9.5	32.4
Soybeans after sweetclover catch crop	I, J, M, N			0.141	1.38	14.9	46.8
Sod Crop Rotations							
Corn	O	1.70		0.12	1.26	11 2	32.3
Soybeans	O			0.12	1.36	9.3	30.3
Wheat	O			0.11		5.0	22.4
Hay	O			0.11	1.51	11.1	41.1
Corn	P	2.08		0.13	1.61	23.4	53.6
Oats	P			0.13	1.79	15 8	43.6
Hay (1)	P			0.14	1.81	20.9	44.7
Hay (2)	P			0.14	1.66	22.3	50.8
Bluegrass border	Check			0.163		47.2	74.8

GENERAL DISCUSSION

Nothing is more completely basic in planning a farm than choosing the rotation of crops to be used. A rotation is defined as the growing of different crops in recurring succession on the same land, as contrasted to continuous culture or a helter-skelter succession of crops. This means that when a rotation is selected for a given farm the number of acres of each crop which will be produced each year is determined, the sources of income are determined, and the livestock which can be kept is very largely determined. Mosher and West (5) in a study of 240 mixed grain and livestock farms in Illinois report that 6.3 percent of the difference ($3,740) in yearly income between the best 72 and the poorest 72 farms was due to the immediate profitableness of the crop system, that is, the rotation used. (The other factors of greater importance were: crop yields 27.5 percent; efficiency in livestock production 11.4 percent; labor cost, 10.3 percent; prices received, 8.5 percent.)

Since the rotation is completely at the foundation of the farm business, changes in rotations are not easily made and are not to be lightly made. One of the basic difficulties with the "acreage control" programs is the way they "mess up" rotations.

Rotations are influenced by many considerations. In the first place, we have the economic reasons for rotations; reasons which would apply if there were no other effects of rotation. We need a variety of crops on the farm in order to distribute labor. Different crops are not harvested or planted at the same time, and consequently one man can take care of a very much larger acreage of rotated land than he can of land that is in a single crop.

The principle of diversification, not "having all one's eggs in one basket basket", is an incentive to rotation, since the vagaries of season do not affect all crops alike, and price changes are different for different crops.

Most Ohio farming is livestock farming rather than crop farming and the crops produced must serve the particular livestock enterprises which are chosen for that farm. This usually requires the growing of several different crops.

Other reasons for rotation involve the common farm pests; weeds, insects, and diseases. These can frequently **compel** rotation of crops. Sugar beets in Ohio cannot profitably be grown more often than once every four years on the same land because if they are grown more often, soil-borne diseases multiply to such an extent that they wipe out the crop.

No classroom or lecture argument for rotating crops has been as potent as the corn failures from southern corn root worm. This insect feeds only on corn and often multiplies to such an extent when corn is grown continuously that in the third year of corn, it mostly blows over in heavy winds.

The great problem of all continuous grain areas has always been the control of weeds. The most famous continuous culture experiment in the world, continuous wheat on Broadbalk Field at Rothamstead in England, is actually not quite continuous culture. Weeds peculiar to winter wheat became so bad that they were obliged to fallow one-fifth of each plot each year in order to clean them up. The rotation actually practiced, recently, has been four years of wheat and one year of fallow. In the continuous corn areas in the Ohio river bottoms, Johnsongrass has made the continuous culture of corn impossible.

Plant pests, then, can **compel** rotation unless we find other means of fighting them. An important new factor in planning rotations involves the new methods of fighting insects, diseases, and weeds, without rotation. Southern corn root worm is being controlled by insecticides applied with the fertilizer for the corn. Weeds in the spring wheat area are being controlled by herbicides on tens of millions of acres. Soil-borne diseases have not yet been chemically conquered at a cost economical for field crops, but have very definitely been conquered by soil treatment for greenhouse crops and similar small areas. These reasons for rotation are becoming less and less important as our technology furnishes other means to control them.

Other reasons for rotation of crops are those factors affecting soil productivity and conservation. These are the factors of most immediate concern to the agronomist.

A bulletin of thirty years ago (10) on crop rotation concluded: "Crop rotation is so important a farm practice, especially in maintaining and increasing the yields of cereal crops, that its effectiveness may often equal or even exceed the effectiveness of complete chemical fertilizer or farm manure." This conclusion was supported by many long time rotation experiments on virgin soils, and this conclusion in one form or another is still a vital part of our farm planning and thinking.

Most of us are aware, but it must be noted first of all, that rotations unsupported by fertilization cannot prevent soil deterioration. Crops, animals, farm products, all contain the essential mineral nutrients necessary for plant life. As these nutrients are removed until they become deficient, they must be replaced, whether crops are grown continuously or in rotation. Rotations which include the nitrogen-fixing legumes can return nitrogen to the soil, but if the mineral nutrients, particularly phosphorus, are not returned as they are removed, the soil will deteriorate, with or without rotation.

On steeply sloping lands, rotations which include long periods of sod crops and short, if any, periods of cultivated crops are essential to soil conservation. It is an open question under present economic circumstances whether cultivated crops have any place on land with more than 8 percent slope. If they must be included on lands more steeply sloping than this, it should not be more often than once in four years, with every precaution known to agricultural science employed to reduce erosion during that one year.

In this report, then, we are considering the level or nearly level soils which, even in Ohio, grow the great bulk of our grain and other cultivated crops. The experiments just reported are clear evidence that proper rotations increase the productivity of the soil. All of the deep-rooted biennial and perennial legumes and mixtures of grasses with them have greatly improved soil productivity. There are three main ways in which they do this: 1. They add nitrogen to the soil; 2. They improve the aggregation and hence the permeability and tilth of the plow layer; 3. They add to the drainability of many subsoils.

In the last few years strident voices have been raised against the necessity of rotation. Some go so far as to say that rotation is outmoded and unnecessary. We may test this claim against each of the three benefits just mentioned.

There is no question but that the nitrogen provided by rotation can also be provided by commercial fertilizer. Whether it is profitable to do so depends on the expense of growing the legume crops and the uses made of them other than as nitrogen gatherers. Those who have cattle or other roughage utilizers to consume the legume hay can build up a farm more economically than anyone else. They can feed the three to five tons an acre of high-nitrogen feed furnished by the legumes in such a way that the liquid as well as the solid excrement is saved to return to the land. They then have a profit from the feed and 100 to 200 pounds of nitrogen per acre per year as a premium. Practically, to be sure, comparatively few livestock men really do this. They permit most of the nitrogen voided to be wasted by leaching and fermentation.

Those farms which are largely or entirely grain farms must re-evaluate legumes as nitrogen producers in terms of the low present-day cost of commercial nitrogen. If not fed as hay or pasture, it is seldom if ever that a legume other than a catch crop can now be profitably used solely as a nitrogen gatherer.

In maintaining or increasing the organic matter of soil and so improving tilth and permeability of the surface soil, there are many loamy soils with comparatively low clay content where nitrogen plus the organic matter produced in roots and tops of grain crops will probably maintain the productivity of the soil. Under the conditions of the experiments under discussion, this has not been done by the methods used. The few experiments reported here by no means settle this question, but the answer which they give so far is definitely that continuous corn, no matter if considerable nitrogen is used, is inferior in yield per acre to the corn in a rotation including a sod crop at least once in four years. The inferiority of continuous corn plus nitrogen is closely proportional to the clay content of the soil. Almost certainly on soil types naturally of better tilth, this difference would not exist. Bear and Salter (2), working on a silt loam soil, found that organic matter and productivity were increased with heavy fertilization even though everything was taken off and no sod crops included. Their emphatic advice was "The best means of maintaining the fertility of the soil is to make it produce large crops" (with fertilizer). There are many soils where this is true and it is partially true on the soils under discussion. Certainly continuous corn with sufficient nitrogen and residues plowed under could be tolerated for a long time with satisfactory returns on the best of these soils; and if it later proved necessary to introduce sod crops, that could always be done. The soils would not be "ruined" and the basis for choice is essentially economic. However, it appears that the soils under discussion will not yield as many bushels of corn or soybeans per acre under continuous culture as they will in a rotation including sod crops. There may, of course, be other than soil factors operating to produce this result.

The third factor in the effect of deep-rooted legumes, the effect on drainability, is the one which we fundamentally know least about. Farm observations of improved drainage after growing deep-rooted legumes have been fairly frequent but are subject to a considerable observational error. Whether the fine-rooted crops like soybeans and corn can substitute for large tap-rooted crops like alfalfa, sweetclover and the clovers is unproven. It is also unproven that they cannot.

There has been a great deal of loose talk about "deep-rooted legumes punching holes in the subsoil". When it comes to improving subsoils with deep-rooted legumes, we learn the truth of the Biblical "To him that hath it shall be given". Tap-rooted legumes on open soils make a large vertical unbranched storage type of root which makes these subsoils still more open and permeable (Fig. 6). Unfortunately, these are the soils which need it least. On tight subsoils with a high proportion

Fig. 6.—Soil type affects form of roots. These samples were taken from Crosby (top) and Brookston (bottom) soils in the same field, everything the same but the soil.

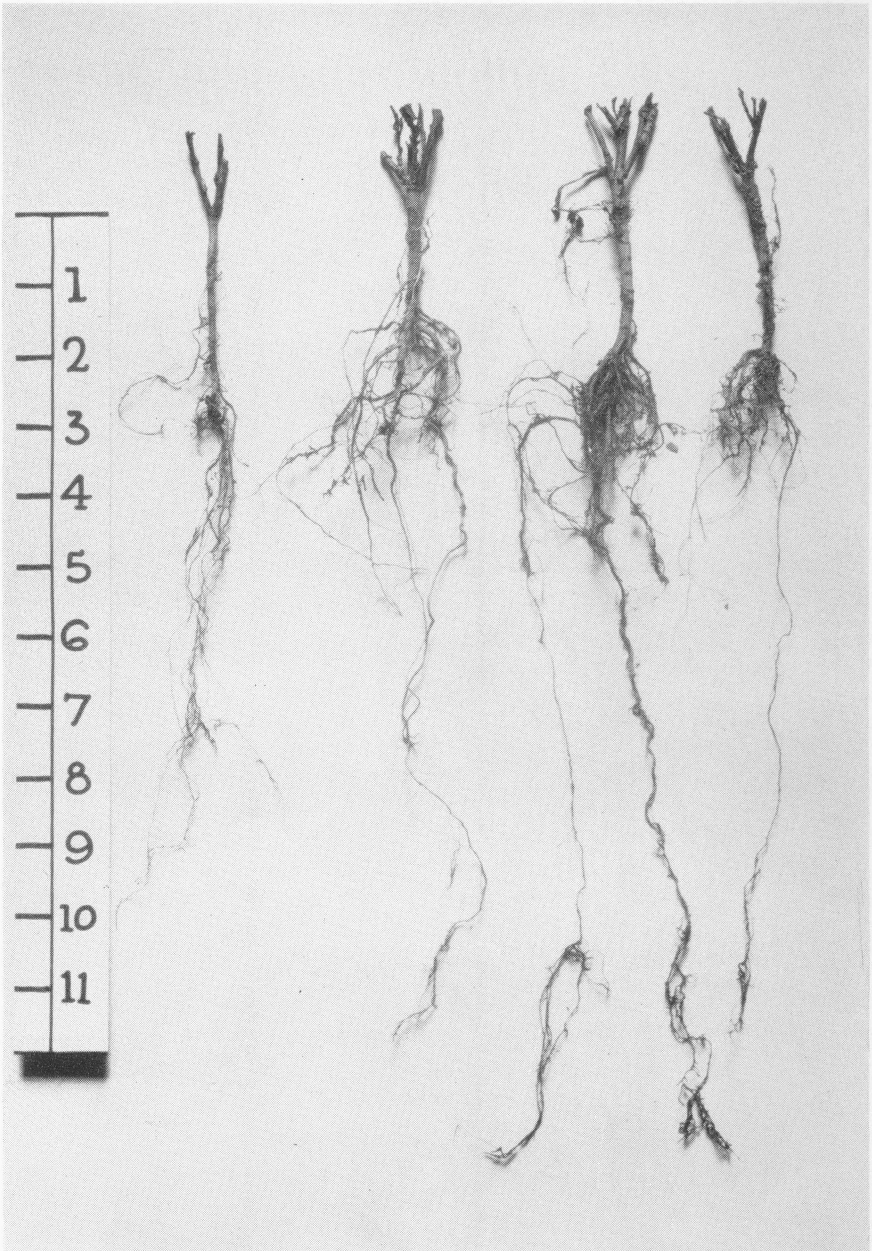

Fig. 7.—First-year alfalfa roots October, on Clermont silt loam. Note that the large storage tap roots extend only 3-4 inches, although the roots extended to 48 inches.

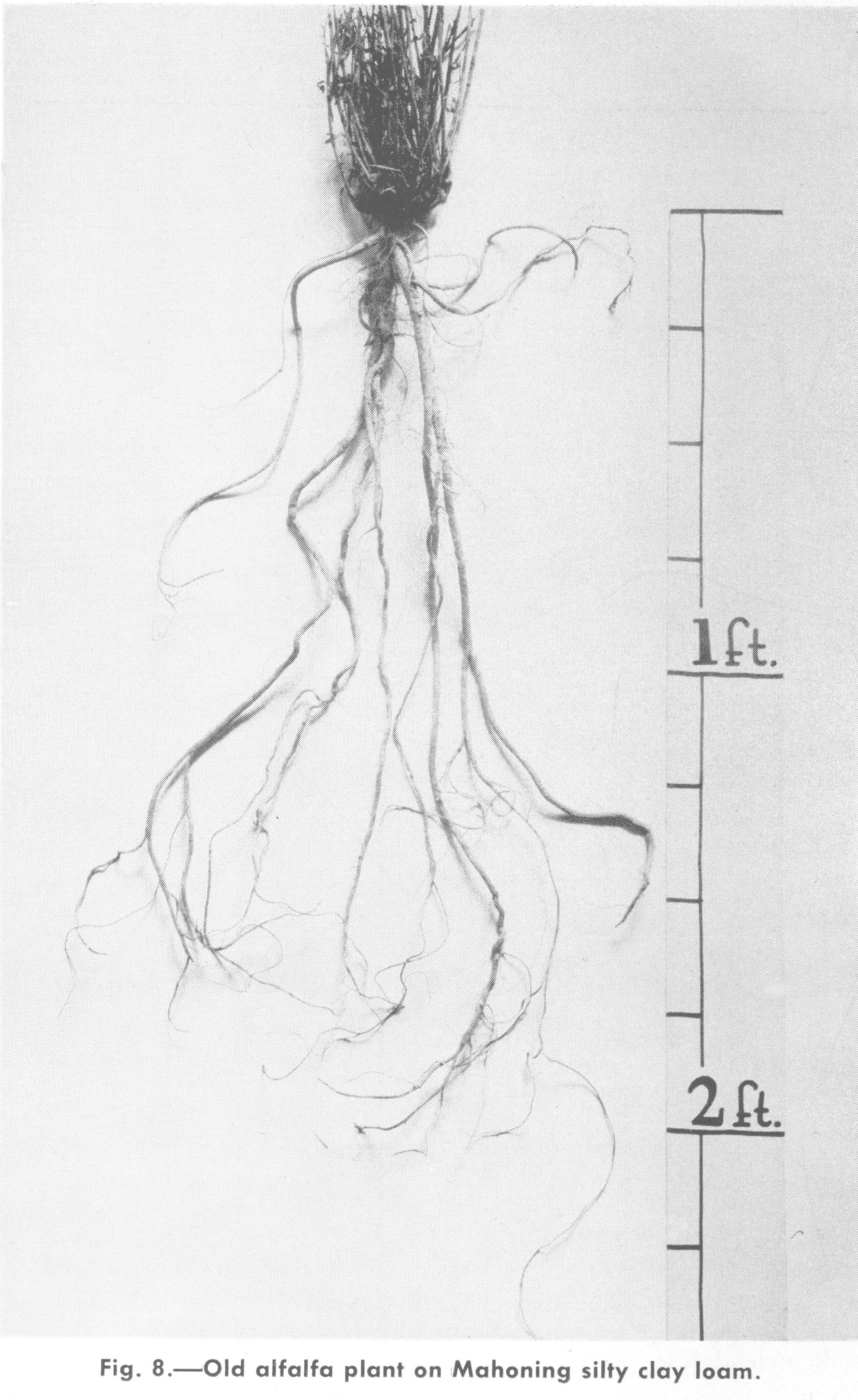

Fig. 8.—Old alfalfa plant on Mahoning silty clay loam.

of clay like the Crosby, Clermont, Mahoning, and Trumbull, not to mention much less permeable subsoils on which we have had no experiments, these same legumes may penetrate as deeply as they do on the other soils, but the roots are fine, branched, crooked, add little organic matter and do little to improve the penetrability and drainability of the subsoil (Fig. 7).

Perhaps if we could leave alfalfa for a considerable number of years, some of these intractable soils would be favorably affected. The author once dug an alfalfa plant on Mahoning silty clay loam at Strongsville (Fig. 8). It was at least seven or eight years old; the exact age was unknown. If we had a good stand of alfalfa with roots like this it would almost certainly have an effect on the subsoil. Unfortunately, this plant was a survivor, with no other plant remaining in a square rod, and the economics of eight years of thin alfalfa is in question.

Nevertheless, though we must be careful not to claim too much for deep-rooted legumes, there are many situations where they seem to be essentially indispensable.